TSUNAMI FORECASTING SYSTEM IMPLEMENTATION: FY2003 PROGRESS AND PROPOSED FY2004 PLANS AND BUDGET

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Contents

Background

The NTHMP has developed and deployed a network of DART systems to provide real-time tsunami monitoring and measurement, and the National Ocean Service maintains a network of coastal tide gauges that are capable of reporting tsunami time series in real time. But inadequate tools exist to interpret these deep-ocean and coastal measurements and forecast the potential impact on coastal communities. An integrated forecast guidance system is needed that combines this measurement technology with state-of-the-art tsunami numerical modeling technology. Model results that match the observations of a sparse network can be viewed as dynamic interpolators in both space and time. This method will provide optimal estimates of tsunami properties in the vast areas of the deep ocean where observations are lacking and at threatened coastal communities. This methodology is not new. Other forecast systems for different natural phenomena – most notably weather and climate forecasting – have used this approach, known formally as data assimilation and inversion, for decades. The implementation of such a system for tsunami forecasting is currently underway, as a collaborative effort of the NOAA TIME Center, the NOAA West Coast and Alaska Tsunami Warning Center, the NOAA Pacific Tsunami Warning Center, and the University of Hawaii Department of Ocean and Resources Engineering. TIME is coordinating this collaborative effort, known as the Short-term Inundation Forecasting of Tsunamis (SIFT) Project.

FY2003 Progress

The NTHMP Steering Group requested that implementation of inundation forecast capabilities be postponed and that SIFT focus first on nearshore forecasting capabilities. Accordingly, the goal of this effort has been to implement an initial version (SIFT V 0.5) by January, 2004. Progress toward this goal is outlined, below.

- <u>Developed implementation plan through two workshops</u>
    - 21 January 2003. Far-field Tsunami Forecast Guidance. Seattle, Washington. Dealt with scientific and technical issues (González, et al., 2003).
    - 13 March 2003. User Follow-up Workshop. Honolulu, Hawaii. Dealt primarily with practical user issues -- Emergency Management and Warning Center.
- <u>Coordinated overall effort through six teleconferences</u> (WCATWC, PTWC, UH/ORE and TIME)
- <u>Identified fundamental TWC System Requirements</u>
    - Must be stand-alone, independent system, resident at TWCs
    - Must be platform independent (WCATWC=PC-WINDOWS; PTWC=Unix)
- <u>Identified major technical issues</u>
    - Build Pacific-wide bathymetric/topographic database and grid
    - Define South Pacific Sources
    - Develop forecast generation/propagation databases
    - Acquire, Pre-process, de-tide data [Connect to NDBC, other data streams and databases; Edit, merge redundant channels, outliers, missing data, …; Remove tidal signal.]
- <u>Specified January 2004 Deliverable (SIFT 0.5)</u>
    - SIFT Graphical User Interface (Short-term Inundation and Forecasting of Tsunamis)
    - Web-based (hence, "quasi-operational")
    - Near-shore Forecast Products
        - TWC Warning Points
        - TWC Tide Gauge Stations
        - Forecast products:
            - At nearest grid cell, in 50 m water depth
            - Time series of wave height in cm and feet
            - Maximum Wave Height (MWH) and/or First Wave Height (FWH)
            - ETA of MWH and/or FWH, in GMT
        - Coverage [Pacific-wide; Bathy/Topo Database V 0.0]
    - Graphics
        - Pacific-wide scale
        - Regional scale [W. Coast; AK; HI; Japan-Kamchatka; TBD: S. Pacific Regions]

        - Local scale
- <u>Completed Tasks</u>
    - Bathy/Topo Database, V 0.5
        - Database implementation plan and report (Venturato, 2003)
        - Data acquisition and Quality Control [ETOPO2 2' and GEBCO 1']
    - Pacific-wide Grid V 0.5
    - TWC Warning Point and Tide Gage lists
    - DART de-tide methodology
        - Analysis of required accuracy (Mofjeld, 2003)
        - Development, testing of two-stage algorithm
        - Software written, tested [Needs SIFT implementation]
    - Draft Graphics (now under review)
    - Automatic First Forecast [Earthquake parameters only]
    - Tests of DART and tide gage inversion methodologies
        - TIME Center [MOST model: '94 Kurile, '96 Andreanov; SIFT implementation]
        - UH/ORE [UH model: '94 Sanriku, '94 &'95 Kuril, '46 Naikai, '44 Tonankai]

Proposed FY2004 Plans and Budget

FY2004 Plans

Two major goals are outlined here -- to implement an initial version, SIFT 0.5, by January 2004, and to implement the next version, SIFT 1.0, by October 2004.

January Implementation of SIFT V 0.5

- Complete MOST Forecast Database [Pacific-wide; Generation/propagation]
- Develop S. Pacific sources
- Test MOST + P-W Grid V 0.0 + New sources
- Establish real-time links to acquire input data [NDBC DART DB; Earthquake parameters]
- Implement SIFT pre-processor [Best Available Time Series; DART tide removal]
- Complete Graphics development
- Implement SIFT Graphical User Interface

October implementation of SIFT V 1.0

- <u>SIFT V 0.5 Plus:</u>
  - Operational: [Stand-alone; in-house TWC; platform independent]
  - Incorporate TWC feedback [EM feedback to TWCs]
  - Coastal forecast [Near-shore => coastline]
  - Statistical forecast [Maximum expected height of Later Waves]
  - Inundation forecast [Five communities: One in each State]
  - Current speed
  - User Quality Guidance [Indices: Inversion, Variability … => Confidence Index ?]
- <u>Some Major Tasks</u>
  - Develop, test, implement Coastline Forecast methodology
  - Establish real-time data stream connection for tide gauge data
  - Implement tide forecast at Warning Points
  - Complete Bath/Topo DB V 1.0 [Improved deep ocean; Fine resolution bathy & topo]
  - Complete P-W Grid V 1.0 [Fine-scale Bathy/Topo grid systems]
  - Develop inundation methodology [Real-time runs ? DB+N-L interpolation ? Neural?]

- Complete Forecast Databases [MOST, UH, WCATWC (?); Design; Develop; Test; Production runs]
- Develop User Quality Guidance Methodology
- Implement SIFT GUI
- Test end-to-end [Historical case studies]

- Some On-Going Tasks and Activities
  - Develop Data Requirements. [To guide upgrades and evolution of NOS tide gauge network, and DART network.]
  - Data Rescue, archiving. [Tide gauge & DART tsunami event data are essential for testing and improving the tsunami forecasting system. Tsunami infrequency makes this urgent.]
  - SIFT Improvements
    - Speed
    - Obvious Error Traps and Warning messages
    - User Judgement Tools: [Edit, revise, re-run]
  - Documentation !
    - Reports, Guides, Articles … [See References, below]

FY2004 Budget

Funding of $156.0K is sought for NTHMP/NOAA shared labor and other costs of 2.0 effective full time (EFT) personnel. This is approximately 54% of the total funding required. The remaining 46%, or $134.3K, will be provided by NOAA.

Item	**NTHMP (K$)**	**NOAA (K$)**	**Totals (K$)**
Labor: 2 Sr. Scientists, Modeler, Modeler Asst., Programmer (2.0 EFT)	156.0	95.3	251.3
Computer		15.0	15.0
Hardware & Software		15.0	15.0
Publications		4.0	4.0
Travel		5.0	5.0
Total Cost	**156.0**	**134.3**	**290.3**

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Appendix A: Data Requirements for Coastal Tsunami Measurements

Technical Requirements.

Sampling:	15-second average values
Reporting:	Every 6 minutes
Communications	GOES uplink with dial-in backup
Coverage:	50-100 U.S. and foreign coastal sites distributed throughout the Pacific basin. A prioritized list is being developed by the NOAA/NWS Tsunami Warning Centers and PMEL for existing stations and for locations to be considered for establishment of new stations. See preliminary list, below.
Survivability:	Resistant to destructive tsunamis
Archiving:	Database of 15-day records for all stations, each record to start 3 days before the tsunami estimated time of arrival.

Programmatic Justification.

NOAA bears national responsibility for tsunami warnings to reduce the loss of life and property. Tsunami data, among others, are explicitly identified as a need in NOAA's FY03-08 Strategic Plan, and guidelines are provided regarding strategies for improving the speed and accuracy of operational capabilities to monitor, understand and forecast hazardous phenomena (see Weather and Water element , Mission Goal 3: Serve Society's Needs for Weather and Water Information). The NOS is responsible for the U.S. network of coastal tide gauges and maintains working relationships with foreign agencies and organizations responsible for similar networks. These networks provide data that are essential for operational tsunami warnings issued to both U.S. and foreign recipients by the NWS Tsunami Warning Centers.

Operational and Scientific Justification.

Modern forecast systems require real-time observations to be integrated with numerical models. Essentially, the model is forced to match the observations, and the model output is then used to predict the phenomena for the region of interest. This methodology for forecasting tsunamis is being implemented by a collaborative effort of the Tsunami Warning Centers and NOAA's Pacific Marine Environmental Laboratory. Improvements are needed to the real-time tsunami data stream if NOAA is to achieve the Strategic Plan goal of increasing the speed, accuracy and reliability of tsunami warnings. The technical requirements listed above are justified by the following operational considerations.

<u>15-second sampling.</u> Maximum tsunami wave height can be seriously underestimated as a result of inadequate sampling. Undersampling is of special concern near the source region, because near-source wave periods tend to be shorter, tsunamis are most destructive, and the first measurement available for hazard assessment and decision-making may very well be a near-source coastal tide gage record. A practical rule of thumb for peak wave detection and accurate waveform definition is to acquire 10-20 samples per wave period. NOS currently provides real-time tsunami data sampled every15-seconds for a number of NOS tide gauges in the Alaska

region, and 15-second samples are stored at a number of other gauges in removable ram-packs for post-event research studies. In principal, the tsunami period band is considered to be in the range of 2-90 minutes, implying full coverage could be achieved with a 7.5- to 15-second sampling period. In practice, however, even shorter sampling periods might be necessary to guarantee full coverage, since significant waves with periods less than 2 minutes have been documented, most notably during the 1983 Japan sea tsunami. Since the technology to provide real-time reports of 15-second is already available, a reasonable first step is the implementation of this technology at all stations.

<u>6-minute reporting.</u> Fatalities are reduced by every minute gained before a warning is issued or updated. Needless warnings are reduced by early determination that a tsunami is non-destructive. Six-minute records of 15-second data will provide tsunami warning center personnel with the magnitude of first tsunami waves with periods 24 minutes or less, and will enable the tsunami forecast system to compute an initial forecast. Subsequent 6-minute records will provide tsunami warning centers with the magnitude of successive peaks and troughs for tsunami waves with periods 12 minutes or less, and enable updated forecasts. Frequent, continuous reports are therefore key to improving the speed and reliability of tsunami warning center operations.

<u>Coverage.</u> Reducing fatalities and needless warnings requires geographic coverage that ensures early detection and measurement. Tsunamis have been and will continue to be generated along more than 9000 km of Pacific Rim coastlines in seismically active regions that include the Alaska-Aleutian Subduction Zone and the Cascadia Subduction Zone off Washington, Oregon and Northern California. Studies are currently underway by the Tsunami Warning Centers and PMEL to develop a prioritized list of tsunami real-time reporting stations needed in support of warning center operations.

<u>Survivability.</u> This is perhaps the greatest engineering challenge, but the need is clear. If shoreline stations cannot be hardened to survive a tsunami, then perhaps the Japanese approach should be explored. They have developed inland systems, known as "Huge-Tsunami Gauges," that are designed to continue collecting and reporting data during a destructive tsunami.

<u>Archiving.</u> Research efforts are critical to improving the speed, accuracy and reliability of tsunami forecasts and NOAA Tsunami Warning Center operations. But there is a paucity of high-quality data available for testing and improving numerical models because, while destructive tsunamis are not rare – a destructive Pacific tsunami occurs each year, on average – they are not common. As a consequence, the tsunami coastal tide gage data are extremely important and valuable. Tsunami waves will reverberate around the Pacific basin, reflecting from boundaries, scattering from topographic features, oscillating in trapped modes along ocean ridges and coastlines, and forcing persistent seiches in ports, harbors and other semi-enclosed basins. This activity gradually decreases, but can persist for 10 days or more. Archived time series should therefore be at least 15 days long, including at least 3 days of data before the tsunami estimated time of arrival, to enable quantitative assessments of pre-tsunami background wave energy and the application of time-varying spectral analysis methods.

Draft List of Priority Tide Gauge Stations.

Station Name & Owner	Priority	Latitude	Longitude
Proposed new sites:			
Seaside/Cannon Beach, OR			
Santa Barbara, CA			
Outer coast, North WA ???			
Prioritized Sites WC/ATWC AOR:			
Seward,_AK_(NOS)	1a	60.119	-149.427
Dutch_Harbor,_AK_(NOS)	1a	53.888	-166.538
Adak,_AK_(NOS)	1	51.863	-176.38
Cordova,_AK_(NOS)	1	60.558	-145.753
Kodiak,_AK_(NOS)	1	57.74	-152.483
Sand_Point,_AK_(NOS)	1	55.333	-160.502
Sitka,_AK_(NOS)	1	57.052	-135.342
Yakutat,_AK_(NOS)	1	59.548	-139.735
Neah_Bay,_WA_(NOS)	1	48.368	-124.617
Port_Angeles,_WA_(NOS)	1	48.125	-123.44
Willapa_Bay,_WA_(NOS)	1	46.705	-123.959
Port_Orford,_OR_(NOS)	1	42.737	-124.497
South_Beach,_OR_(NOS)	1	44.625	-124.043
Arena_Cove,_CA_(NOS)	1	38.913	-123.705
Crescent_City,_CA_(NOS)	1	41.745	-124.183
La_Jolla,_CA_(NOS)	1	32.867	-117.258
Los_Angeles,_CA_(NOS)	1	33.719	-118.272
Monterey_Harbor,_CA_(NOS)	1	36.605	-121.888
North_Spit,_CA_(NOS)	1	40.767	-124.217
Point_Reyes,_CA_(NOS)	1	37.997	-122.975
Port_San_Luis,_CA_(NOS)	1	35.168	-120.753
San_Francisco,_CA_(NOS)	1	37.807	-122.465
Santa_Monica,_CA_(NOS)	1	34.008	-118.5
Ketchikan,_AK_(NOS)	2	55.333	-131.625
Seldovia,_AK_(NOS)	2	59.437	-151.717
Valdez,_AK_(NOS)	2	61.125	-146.362
Friday_Harbor,_WA_(NOS)	2	48.547	-123.007
Port_Townsend,_WA_(NOS)	2	48.101	-122.758
Charleston,_OR_(NOS)	2	43.345	-124.322
Alameda,_CA_(NOS)	2	37.772	-122.298
San_Diego,_CA_(NOS)	2	32.713	-117.173
Anchorage,_AK_(NOS)	3	61.238	-149.888
Juneau,_AK_(NOS)	3	58.289	-134.412
Nome,_AK_(NOS)	3	64.5	-165.43

Prudhoe_Bay,_AK_(NOS)	3	70.388	-148.51
Cherry_Point,_WA_(NOS)	3	48.863	-122.758
Seattle,_WA_(NOS)	3	47.602	-122.335
Tacoma,_WA_(NOS)	3	47.3	-122.5
Astoria,_OR_(NOS)	3	46.208	-123.767
Port_Chicago,_CA_(NOS)	3	38.057	-122.038
Sites PTWC AOR (Not Prioritized):			
Cocos_Islands,_Australia_(AUST2)	A	-12.12	98.88
Rarotonga,_Cook_Is_(AUST2)	A	-21.2	-159.783
Kings_Wharf,_Fiji_(AUST2)	A	-10.52	141.47
Lautoka,_Fiji_(AUST2)	A	-17.6	177.43
Tarawa,_Kiribati_(AUST3)	A	1.35	172.92
Majuro,_Marshall_Is_(AUST3)	A	7.117	171.37
Nauru_(AUST2)	A	0.05	166.9
Manus,_PNG_(AUST2)	A	-2.03	147.367
Jackson_Bay,_New_Zealand_(AUST2)	A	-43.975	168.615
Honiara,_Solomon_Is_(AUST2)	A	-9.417	159.95
Apia,_West_Samoa_(AUST3)	A	-13.817	-171.75
Nukualofa,_Tonga_(AUST2)	A	-21.133	-175.17
Funafuti,_Tuvalu_(AUST2)	A	-8.5	179.2
Port_Vila,_Vanuatu_(AUST2)	A	-17.75	168.3
BuoyD125_8S_125W_(NOS)	D	-8	-125
BuoyD128_45N_128W_(NOS)	D	45.86	-128.772
BuoyD130_42N_129W_(NOS)	D	42.3	-129.568
BuoyD157_53N_157W_(NOS)	D	53	-157
BuoyD165_52N_165W_(NOS)	D	52	-165
BuoyD171_48N_171W_(NOS)	D	48	-171
Snug_Harbor,_Oahu,_HI_(HANDAR)	H	21.318	-157.885
French_Frigate_Shoal,_HI_(HANDAR)	H	23.783	-166.217
Antofagasta,_Chile_(HANDAR)	H	-18.472	-70.335
Arica,_Chile_(HANDAR)	H	-18.472	-70.335
Caldera,_Chile_(HANDAR)	H	-27.058	-70.834
Coquimbo,_Chile_(HANDAR)	H	-29.93	-71.35
Corral,_Chile_(HANDAR)	H	-39.867	-73.43
Iquique,_Chile_(HANDAR)	H	-20.22	-70.17
Juan_Fernandez,_Chile_(HANDAR)	H	-33.617	-78.825
Puerto_Mont,_Chile_(HANDAR)	H	-41.967	-72.97
Puerto_Williams,_Chile_(HANDAR)	H	-54.933	-67.611
Punta_Carona,_Chile_(HANDAR)	H	-41.783	-74.883
San_Antonio,_Chile_(HANDAR)	H	-33.583	-71.63
San_Felix,_Chile_(HANDAR)	H	-26.258	-80.124
San_Pedro,_Chile_(HANDAR)	H	-47.717	-74.883

Talcahuano,_Chile_(HANDAR)	H	-36.683	-73.1
Valparaiso,_Chile_(HANDAR)	H	-33.033	-71.617
Cabo_San_Lucas,_Mexico_(HANDAR)	H	22.883	-109.9
Callao,_La_Punta,_Peru_(HANDAR)	H	-12.071	-77.174
Lobos_de_Afuera,_Peru_(HANDAR)	H	-6.935	-80.72
Baltra,_Galapagos_(HANDAR)	H	-0.433	-90.283
Betio,_Tarawa,_Kiribati_(HANDAR)	H	1.358	172.933
Chatham,_New_Zealand_(HANDAR)	H	-43.941	-176.557
Christmas_Is,_Kiribati_(HANDAR)	H	1.984	-157.473
Easter_Island_(HANDAR)	H	-27.15	-109.448
Johnston,_USA_(HANDAR)	H	16.738	-169.525
Kanton,_Kiribati_(HANDAR)	H	-2.801	-171.718
Kapingamarangi,_Micronesia_(HANDAR)	H	-1.085	154.768
Legaspi,_Philippines_(JMA)	H	13.1611	123.7578
Majuro,_Marshall_Is_(HANDAR)	H	7.107	171.373
Malakal,_Kuror,_Palau_(JMA)	H	7.332	134.464
Niue,_Niue_(HANDAR)	H	-19.0525	-169.921
Noumea,_New_Caledonia_(HANDAR)	H	-22.285	166.433
Nuku_Hiva,_Fr._Polynsia_(HANDAR)	H	-8.918	-140.068
Penrhyn_Micronesia_(HANDAR)	H	-9.001	-158.051
Pohnpei,_Cook_Is_(HANDAR)	H	7	158.218
Rarotonga,_Cook_Is_(HANDAR)	H	-21.192	-159.769
Santa_Crux,_Galapagos_(HANDAR)	H	-0.752	-90.307
Wake_(HANDAR)	H	19.29	166.618
Yap,_Micronesia_(JMA)	H	9.512	138.128
Ust_Kamchatsk_(GMS)	J	56.2	162.5
Servero_Kurilsk_(GMS)	J	50.8	156.1
Hanasaki,_Japan_(JMA)	J	43.28	145.57
Naha,_Japan_(JMA)	J	26.22	127.67
Ofunato,_Japan_(JMA)	J	39	141.75
Omaezaki,_Japan_(JMA)	J	34.6	138.23
Tosashimizu,_Japan_(JMA)	J	32.78	132.92
Hilo,_Hawaii,_HI_(NOS)	N	19.733	-155.058
Honolulu,_Oahu,_HI_(NOS)	N	21.307	-157.867
Kahului,_Maui,_HI_(NOS)	N	20.898	-156.472
Kawaihae,_Hawaii,_HI_(NOS)	N	20.036	-155.832
Mokuoloe,_Oahu,_HI_(NOS)	N	21.437	-157.793
Nawiliwili,_Kauai,_HI_(NOS)	N	21.957	-159.36
Diego_Ramirez,_Chile_(NOS)	N	-57	-67.267
Manzanillo,_Mexico_(NOS)	N	19.062	-104.252
Guam,_USA_(NOS)	N	13.438	144.652
Kwajalein,_Marshall_Is_(NOS)	N	8.735	167.736

Midway,_USA_(NOS)	N	28.207	-177.356
Pago_Pago,_Am_Samoa_(NOS)	N	-14.274	-170.676
Papeete,_Tahiti_(NOS)	N	-17.533	-149.567